CONSEQUENCE ANALYSIS OF HYDROGEN STORAGE TANK FACILITY: A CASE STUDY APPROCH BY USING PHAST

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ABSTRACT

Major industrial accidents such as Sevoso disaster (1976), Bhopal gas tragedy (1984), Piper alpha (1988), Oil spill in gulf of Mexico (2010) are made huge impact. These accidents could have been avoided if safety precautions are followed during design, operation and maintenance. Risk Assessment is one of the main tool used in process industries to minimize the risk. This paper describes the methodology followed for the consequence assessment of hydrogen storage & handling facility. Consequence assessment is an integral part of risk assessment. Earlier days spread sheets and calculations by manually to estimate the blast over pressure and radiation intensity from any fire or explosion situations. Now a days sophisticated software models are used to assess the risk of the process plants and especially for consequences analysis. In this work Process Hazard Analysis Software Tool (PHAST) is used for consequence analysis of hydrogen run tank and unloading activity. The consequences such as Jet Fire, Boiling Liquid Expanding Vapor cloud Explosion (BLEVE) etc have been modeled. This study output is compared with traditional manual calculation of TNT equivalent of approach. Based on the study people around the facility within 97 m is considered as vulnerable they have to be evacuated during transfer operation. Minor damage may occur to the structure around the facility approximately up to 110 m. These results are used for further land use planning or providing adequate protection for existing facilities. In this paper an attempt has been made to give a brief overview of consequence analysis, the methodology and how this analysis output to be used for facility site, planning for any emergency.

KEYWORDS: Risk Assessment, Jet Fire, BLEVE, Consequence Analysis

INTRODUCTION

The rapid growth in industries not only develops the economy of one country and also leads to various hazards or accidents. The process industry accidents are differing from other industrial accidents, because of their consequence effects with the potential to cause disaster.Today any process industries handling minor or major quantity of hazardous chemicals and ready to prepare to identify the hazards and ready for in case of any emergency. Quantification of hazards is very important for various purpose such as to understand the magnitude of accident, Damage potential inside and outside of the facility, Major/Minor events possible and Preparedness for emergency plan and procedure. In general the process industry the leak of any hazardous materials results consequences of Fire, Explosion and Toxic effects or combination of these which is depends up on the material.

Fire and explosion consequences are applicable for this hydrogen storage facility as this loading and facility is in the open atmosphere. According to A.R. Soman (2012) vapor cloud explosion is one of the accident scenario in case of hydrogen leak from the hydrogen holder. The effects are interpreted in terms of thermal radiation due to fire and pressure

waves due to explosion. According to Rigas. F (2004) depending of the type of levels of substance concentration, thermal radiation intensity, over pressure were calculated at the distance of our interest. Henk W.M empathized that the Consequence analysis models are included in TNO yellow book (TNO, 1997) and Sections 16-17 of Lees (1996) and the CCPS guidelines (CCPS, 1994).

The risk assessment of any industry which involves qualitative and quantitative assessment of risk posed. The cause of any possible leak of hazardous chemical or loss of containment critically examined. As per Sergio. C (2010) different approaches and methodologies are applied in each step of risk assessment process. As per Z.Y. Han et al (2011), risk assessment is defined as a mathematical function of the probability and consequence of an accident. Consequence analysis is a step and an integral part of risk assessment. These assessments are carried out during the initial phase of process facility in the design stage

The quantification of these chemicals involves a range of engineering principles and properties of the chemicals involved and the atmospheric conditions during release. M. Demichela et al (2004) indicated that correct and careful risk analysis is necessary to formulate and implement safety management system in chemical plants. Consequence modeling used to guide engineering solutions, safety system design, and emergency planning arrangements rather than without full QRA study. Gareth Book (2007).

MATERIAL &METHODOLOGY

The risk assessment methodology is described below. Risk assessment involves the following five steps in general.

- Hazard Identification or analysis

- Frequency analysis

- Consequence analysis

- Risk evaluation or estimation.

- Risk reduction or mitigation

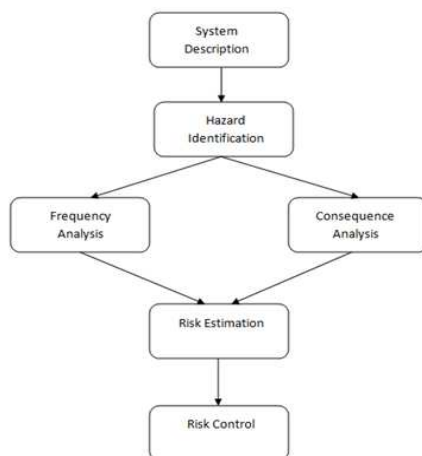The typical flow diagram of risk assessment methodology is shown in Figure 1.

Figure 1: Typical Risk Assessment Flow Diagram

Hazard Identification or Analysis

This is the first step of risk assessment. In this the various sources of hazards and different leak scenarios are identified and how the mechanism of leak and its effects. Z.Y Han et al. (2011) pointed out various qualitative hazard identification techniques. Few examples are

- Check list,

- HAZID

- Safety audit,

- MOND index

- DOW Fire& explosion index

- Chemical exposure index

- HAZOP

- FMEA.

In this study the checklist methods is used to find out the various hazards in the operation. Being as a process plant the operational hazards are identified using HAZOP study. Based on the hazard identification and HAZOP study the Maximum credible loss scenarios are selected for further quantitative risk assessment.

System Description

The design of the hydrogen loading system is well developed and has been the subject of substantial review. The loading is followed by standard operating procedure.

A line diagram of a simplified hydrogen loading from a road tanker to the run tank is shown in Figure 2.The road tanker is parked in the tanker parking area. The fill line and pressurization line connected to the road tanker. The pressurization line is connected from gaseous hydrogen cylinder to the hydrogen road tanker. The fill line is connected between hydrogen road tankers to hydrogen run tank. The road tanker is pressurized up to 1.5 bar and the hydrogen is transferred from road tanker to run tank.
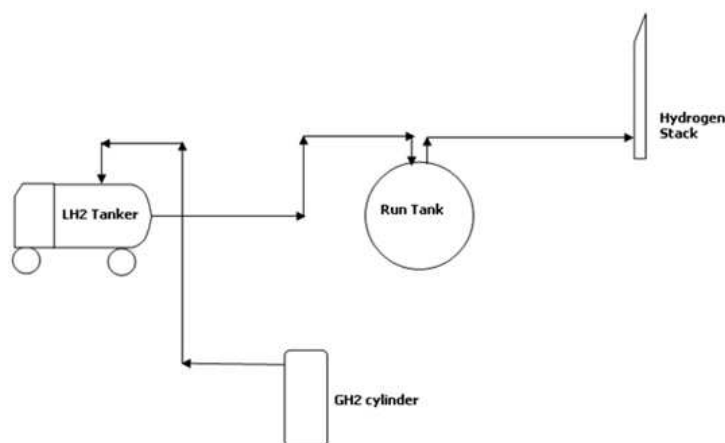

Figure 2: Loading of Hydrogen from Road Tanker to Storage Tank

The fill line and the storage tank were having the safety system to take care of over pressure during transfer operation.

Scenario Selection

Liquid hydrogen is a cryogenic fluid and gaseous hydrogen poses fire and explosion hazards. Liquid hydrogen and hydrogen gas are colorless, odorless and tasteless. Hence, they are difficult to detect by naked eye. The liquid hydrogen produces large volume of gas on vaporization if it leaks. Pressure will rise rapidly in the pipelines and vessels which are not properly insulated.

Liquid and gaseous hydrogen will mix with air very fast and requires very small energy to ignite. Hydrogen forms combustible/explosive mixtures with air or O2 depending upon the confinement and ignition source. Obstructions like burr in the flow path in H2 and O2 systems may lead to localized heating and associated hazards like fire or explosion. The main hazards involving with hydrogen are Fire, Explosion, Violent combustion reaction with oxygen, chlorine, fluorine.

Many leak scenarios have been conceptualized based on hazard identification study, Critical consequence outcome cases of HAZOP study, Event tree analysis and hazardous properties of liquid hydrogen and gaseous hydrogen. Consequence analysis of risk assessment varies by many parameters, such as released volume, release rate, release direction, probability of ignition, time of ignition, and events associated with ignitions are considered. EelkeS.Kooi et.al. (2013). Based on all the hazard identification study the following five scenarios are considered for this study.

Scenario: Leak from the input liquid hydrogen line from road tanker to storage tank in the facility during loading operation.

Scenario: Leak from the liquid hydrogen storage tank; a hole in run tank is considered.

Scenario: Leak from the liquid hydrogen storage tank; catastrophic failure of storage tank.

Scenario: Leak from gaseous hydrogen line from gaseous hydrogen cylinder to road tanker.

Scenario: Leak from the liquid hydrogen tank output line to the test equipments at the facility during testing operation.

Metrological Information

The effect zones due to any accident release of hydrogen will depend up on many factors such as the quantity of material, phase of the hydrogen, atmospheric stability class, wind speed, direction, etc. During summer the temperature reaches 37^0C and winter month's average temperature reaches 25^0C. The relative humidity varies between 70-85 % over summer and winter periods. The prevalent wind directions are West-East-North direction. All these information have been taken from meteorological station installed at site. The solar radiation and cloud amount at the time of accident largely controls the effect zone and according to the site conditions the assumptions have been made.

The physical state of the atmosphere is usually followed by Pasquill-Gifford. The software considers the following three categories for analysis purpose they are category 1.5 F, category 1.5 D, Category 5 D. Due to various wind speed and various stability classes and combination of various scenarios leads to more number of calculation which require sophisticated software for calculation. Jeffrey .D. Marx (2001)

Reputed software PHAST 6.5.1 and SAFETI Micro V 6.5.1, LEAK, NEPTUNE, CRASH models developed by DNV, UK is used for evaluation of risk. Ramesh babu J. et. al (2009) Gareth Book (2007). In this study Process hazard analysis software tools (PHAST) is used for modeling the consequence. The consequence outcome cases such as pool fire, jet fire, flash fire, vapor cloud explosion, unignited dispersion, BLEVE and toxic release are able to model by this software. The results are produced as chart, graphs and contours. Based on the results & risk acceptance criteria further assessment is to be carried out. Dr. Nic. (2001).

DISCUSSIONS

Leak from pipelines, tanks lead to Jet fire, vapor cloud explosion, BLEVE scenarios considered for consequence analysis.Georges A. Melhem (2006) indicated that radiant heat from fire (Kw/m2) and radiant heat dose from BLEVE (KJ/m2) and Over pressure from explosions (bar) and Toxic exposure (PPM) levels are evaluated to how the level of injury to the humans. The catastrophic liquid hydrogen tank failure scenarios is the maximum credible accident which results had been discussed in this paper. The table 1 shows the radiation level intensity and its physical effects in case of any type of fire or explosion scenarios.

Table 1: Heat Radiation Level & Its Effect

Radiation Level (KW/M^2)	Physical Effect
37.5	Sufficient to cause damage to process equipment and death to humans.
25	Minimum energy required to ignite wood at indefinitely long exposure.
12.5	Minimum energy required to piloted ignition of wood, melting of plastic tubing, 50 % damage level.
9.5	Pain threshold reached after 8s; second degree burns after 20 seconds.
4.0	Sufficient to cause pain to personnel if unable to cover the body within 20seconds; however blistering of the skin is likely; with no lethality.
1.6	Will cause no discomfort for long exposure.

The table 2 shows the over pressure and its effects in case of any vapor cloud explosion or Boiling liquid expanding vapour cloud explosion and its effects on humans and environment.

Table 2: Explosion Overpressure Effects

Pressure (PSI)	Damage Effect by Blast
1.0	Partial demolition of houses, Made uninhabitable
2.0	Partial collapse of walls and Roofs of Houses
3.0	Steel frame buildings distorted and pulled away from foundation.
4.0	Cladding of light industrial buildings ruptured
5.0	Wooden utility poles snapped; tall hydraulic press in buildings slightly damaged.
7.0	Loaded train cars overturned.
9.0	Loaded train box cars demolished.
10.0	Probable total building destruction; heavy machine tools moved and badly damaged
14.5-29	Range for 1-99% fatalities among exposed populations due to direct blast effects.

Calculation of Overpressure and Fire ball

TNT equivalent method is followed in manual calculation to assess the safety distance from the different facilities as per US Army Material Command Regulations (No.385-100). TNT equivalent is taken as 60 % of total weight of the

hazardous materials handled.

The Blast Pressure at Various Distances is Calculated by using the Following Equation

- P = 2.69 W0.4 R –1.2

- Where   P - Max. over pressure in kg/cm2

- W - TNT Equivalent in kg = 12342 kg

- R - Distance in meters.

Peak over Pressure Values at Various Distances of Our Interest are Given Below

- Barricaded Intra line distance   = 0.556 kg /cm2 (86 m)

- Unbarricaded intra line distance   = 0.242 kg /cm2 (172 m)

- Inhabitation distance   = 0.092 kg /cm2 (383 m)

- Control Room distance   = 0.285 kg /cm2 (150 m)

In case of accidental mixing of the propellants the fire ball diameter, its duration and blast pressure levels at various distances are as follows:

- Equivalent Fire ball diameter, D = 9.56 W 0.325

- where   D - in feet (the standard error is 30%)

- W - wt. of the oxidiser& fuel in lbs. = 20568.0 kg = 27646 lbs

- D = 9.56 * 276460.325

- = 265.45 ft   = 82 m

Hence, maximum fire ball diameter will be 106 m.

From these calculations safety distances for other facilities and emergency evacuation of personnel adjacent facilities are evaluated and during hydrogen transfer operations it is implemented.

RESULTS

Maximum concentration level of hydrogen gas based on lower explosive limits (LFL) in 100% LFL and 50 % of LFL are plotted in the footprint in figure 3. The cloud width and distance are mentioned based on down wind direction.
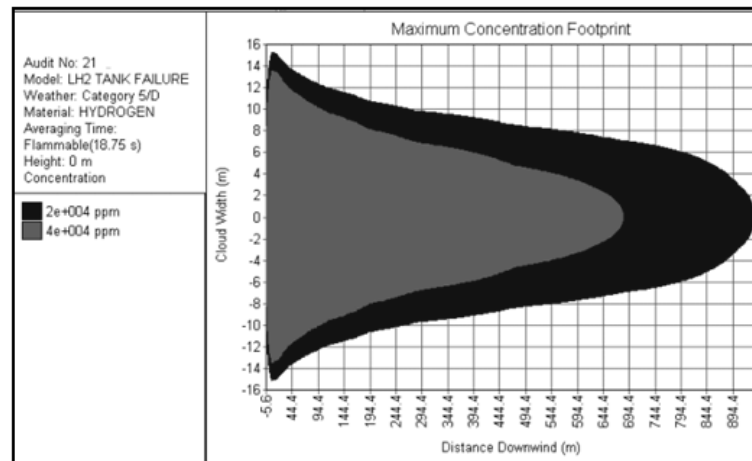
Figure 3: Maximum Hydrogen Concentration in Ppm in Downwind Direction

The figure 4: shows the various heat radiation intensity levels around the hydrogen facility. The three contours represent the radiation levels 4 KW/m², 12.5 KW/m², 37.5 KW/m² respectively.
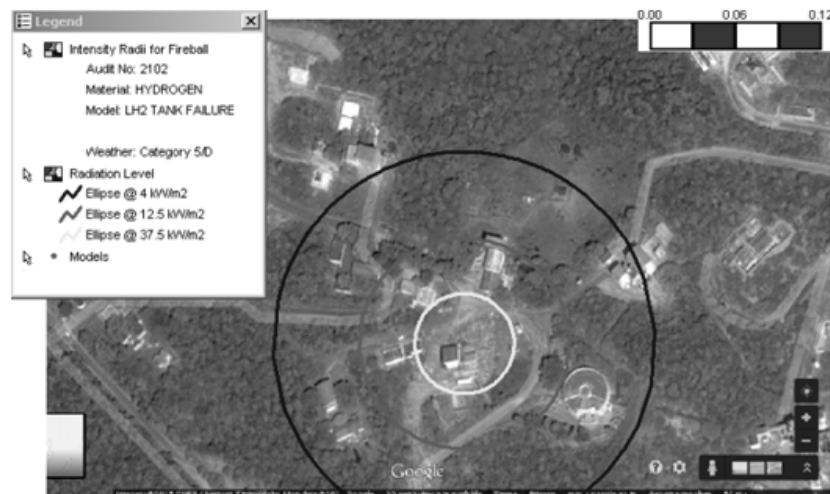

Figure 4: Radiation Intensity Contour for Catastrophic Failure

The table -3 indicates 35 meter around radius the heat intensity reaches maximum level and lower intensity of 4 KW/m² spread across a distance of 135 m.

Table 3: Radiation Intensity with Distance

Scenario	Maximum Distance Affected by the Radiation Level (in Meter)				
	4.0 KW/m²	9.5 KW/m²	12.5 KW/m²	25.0 KW/m²	37.5 KW/m²
Catastrophic Failure of liquid Hydrogen run tank	135 m	97 m	70 m	46 m	35 m

Over Pressure from the hydrogen tank catastrophic rupture is shown in figure 5. as shown below. The peak pressure reaches immediately after the explosion and decreases over time and distance.
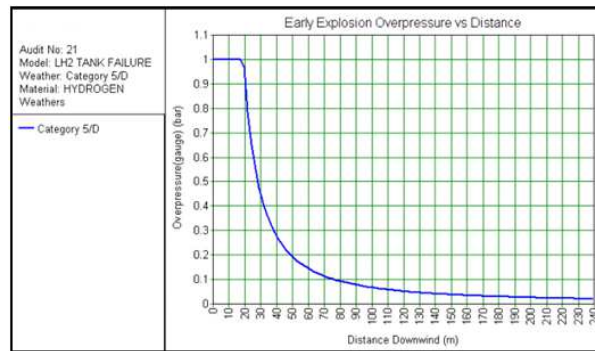
Figure 5: Over Pressure with Distance Chart

The table 4: indicates the distance which the overpressure reaches from 1 psi to 14 psi is mentioned.

Table 4: Over Pressure with Distance from Point of Explosion

Scenario	Maximum Distance Affected by the Over Pressure Wave in Meter				
	1 Psi	2 Psi	4 Psi	7 Psi	14 Psi
Catastrophic Failure of liquid Hydrogen run tank	110 m	60 m	40 m	28 m	18 m

Risk Mitigation Measures

A.R Soman et al (2012) emphasized that due to invisible nature of hydrogen flame suitable gas and flame detector to be installed over hydrogen holder and other leak sources. The protection system for hydrogen transfer facility such as Hydrogen Leak detection & Monitoring system, Fire detection system, Fire protection system deluge system for test facility, Fire protection system such as sprinkler system, Fire hydrants & automatic fire monitors etc. These safety and fires protection system readiness & operation is vital for safe operation of the facility. Apart from the above design safety requirements the following measures also to be implemented to reduce risk level.

- Enforment of regular maintenance of equipments

- Development of safety culture

- HSE audit &implementation of recommendation

- Specific HSE trainings

- Emergency plan update &conduct of Mock drills

Ray J Davieset. et.al (2009) study pointed out how the risk assessment recommendations are to integrate with safety management system and how to improve the safety on pipeline network. Spyros sklavounos and FotisRigas.(2006)indicated that based on the risk assessment findings, safety distance from natural gas pipelines are established. It is used in emergency response planning and as well as safer-land use.

CONCLUSIONS

This work presented here is a brief view of how consequence analysis is carried out in hydrogen tank facility. It should be understand that there many scenarios may happened during the operation. The maximum worst accident case

scenario is selected and over pressure and radiation intensity are calculated. Based on software model and manual calculations are compared. It has verified that the manual calculations are given adequate safety factor and distance are within calculated values.

Based on the radiation heat contour and overpressure from the hydrogen tank explosion, approximately 97.5 m distance the people needs to be evacuated. The people working adjacent to the tank area such as other test facility, storage, and security rooms are to be demarked as vulnerable zones. These areas are to be evacuated during hydrogen transfer operation.

In this present study three wind speeds & 2 classes are used for modeling. The future study may carry out more wind speed & classes are to use for modeling. The study will be extended as quantitative risk assessment (QRA) & assess the individual and societal risk from the hydrogen tank facility.

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